

Effect of neutron damage on detector signal shapes

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Fast neutrons damage the lattice structure of germanium radiation detectors by introducing hole traps. This results in a decrease of charge collection efficiency and a degradation of the energy resolution of the detector [1, 2].

For tracking detector such as GRETINA, it is important to understand if neutron damage degrades also the features of the pulse shape, limiting the position resolution and therefore the performance of the array. It has been estimated that for the GRETINA detector a position resolution of 1-2 mm could be achieved, which is limited by physics factors such as Compton profile (electron momentum) and the finite range of primary electron in germanium. Our interest is to know the amount of neutron damage corresponding to a position error of 1-2 mm.

The effect of neutron damage has been introduced in the pulse shape simulation code through a parameterization of the charge collection efficiency. The number of holes created by the γ -ray interaction decreases [2] as the holes travel towards the collecting electrode as:

$$n = n_0 \cdot \exp\left(-\frac{\Delta r}{\lambda_h}\right)$$

where n_0 is the initial number of holes, λ_h is the hole mean free drift length and Δr is the distance traveled by the holes. No electron trapping is assumed in the model.

The mean free path depends on amount of traps, crystal type (n- or p- type), applied bias, detector temperature, and temperature history. It is expected to be inversely proportional to the neutron fluence and to vary with the electric field as:

$$\lambda_h(r) = \lambda_h \frac{E(r)}{E_c}$$

where E_c is a normalization constant ($E_c = 2000$ V).

The relationship between neutron fluence and λ has been experimentally measured [3]. At a temperature of 95 K the mean free path of holes corresponding to a fluence of 10^9 neutron/cm² is about 100 cm.

The effect of hole trapping on energy and position resolution has been studied as a function of the trapping length λ , in the range from 100 cm to 10 cm, using simulated pulse shapes. The GRETINA prototype detector was used as model in the simulations. It has the shape of a regular hexagon (8 cm diameter, 9 cm length, 10 degree tapering) and is 36-fold segmented [4]. Pulse shapes from the 36 channels have been calculated for a number of interaction points (over 500) covering one segment of the detector, considered as representative segment. The energy is calculated from the signal amplitude; the position resolution is calculated from the difference between pulse shapes with a given λ and reference pulse

shapes ($\lambda=\infty$), corresponding to the same interaction position.

Hole trapping results in two effects: 1) reduction of the collection efficiency; 2) the charge induced on the neighboring segments does not integrate to zero; the net charge contribution from all the segments has to be added to the amplitude of the net charge signal.

The energy loss due to hole trapping is a simple function of the distance traveled by the hole. Therefore, knowing the position of the interaction, it is possible to use an empirical formula to recover the energy resolution of the detector.

Fig. 1 shows the energy resolution before and after correction and the position resolution as a function of the trapping length λ . The energy resolution is given by the FWHM of the peak shape. Neutron damage degrades both the energy and the position resolution of the detector, but the worsening of the position resolution is much slower. If no correction is applied, the critical energy resolution (~ 3 keV, at this energy resolution annealing is required) is reached for $\lambda \leq 70$ cm. If the energy loss is corrected for the interaction position, $\Delta E \sim 3$ keV for $\lambda \sim 30$ cm, this means that the detector can be exposed to neutron for a much longer time (more than a factor of 2). The position resolution corresponding to a trapping length of 30 cm is 0.4 mm, i.e. still better than the specification. From these results, it can be concluded that neutron damage will not affect the capability of reconstructing the position of the interaction from the features of the pulse shapes, before the detector has to be annealed to recover energy resolution.

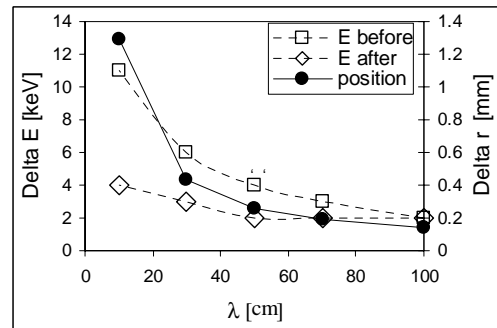


FIG. 1: Energy resolution vs. λ , before (squares) and after (diamond) correcting for the interaction position.

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